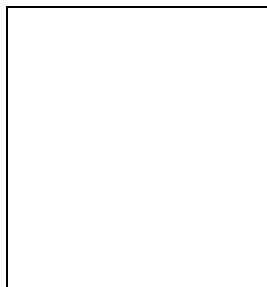


RESULTS ON ψ' PRODUCTION IN NUCLEUS–NUCLEUS COLLISIONS AT CERN-SPS

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We report results on ψ' production as a function of centrality as measured by experiment NA50, at the CERN/SPS, in Pb-Pb collisions at an incident energy of 158 GeV per nucleon.

1 Introduction

Charmonia production in proton–proton, proton–nucleus and nucleus–nucleus collisions has been addressed since the mid 80s by the NA38 and the NA50 experiments. The yield of $c\bar{c}$ bound states in such interactions can be affected by absorption in nuclear matter or, potentially, by

Table 1: Summary of the data samples presented here.

<i>Data taking period</i>	<i>Target thickness</i>	<i>Number of subtargets</i>	<i>Beam intensity (ions/burst)</i>	<i>Number of J/ψ</i>	<i>Number of ψ'</i>
1998	$7\%\lambda_I$	1 (in air)	$5.5 \cdot 10^7$	49000	380
2000	$9.5\%\lambda_I$	1 (in vacuum)	$7.0 \cdot 10^7$	129000	905

interactions with hadrons produced in the collision. Moreover, according to non-perturbative QCD predictions, ultrarelativistic nucleus-nucleus collisions could lead to a phase transition of normal nuclear matter to a quark-gluon deconfined state (QGP) inducing, through the so-called *Debye colour screening*¹, a specific suppression of the production of the J/ψ bound state. The NA50 experiment has already measured a significant abnormal J/ψ suppression in Pb-Pb collisions^{2,3}. Within this framework, the production of ψ' has also been measured although, as a more loosely bound state, it is expected to be much less specific of a phase transition.

2 Data selection and analysis method

The NA50 apparatus⁴, an upgrade of the previous NA38 detector, is designed to detect and measure muon pairs in an air gap toroidal magnet muon spectrometer. The centrality of the collision can be estimated from a Multiplicity Detector (MD) measuring the charged multiplicity of the interaction, an Electromagnetic Calorimeter (EM) measuring the neutral transverse energy E_T , or a Zero-Degree Calorimeter (ZDC) measuring the beam ion spectators energy E_{ZDC} .

The Pb-Pb data used for the ψ' analysis reported here were collected in 1998 and 2000, with a Pb ion beam impinging on a single Pb target, placed in air in 1998 and in vacuum in the 2000 setup. Dimuons are selected in the rapidity range $2.92 \leq y_{lab} < 3.92$ ($0 \leq y_{CM} < 1$) and with a Collins-Soper angle $|\cos \vartheta_{CS}| < 0.5$, leading to an acceptance of $\sim 14\%$ in the dimuon invariant mass region of interest. After rejecting upstream interactions and the residual pile-ups by means of dedicated detectors, on-target interactions are identified requiring the appropriate correlation between hits in the MD and applying proper track quality cuts (see³). A summary of the analyzed sample is given in Table 1. The events are analyzed as a function of the interaction centrality. In each centrality class the opposite-sign dimuon mass spectrum results from four physical components (J/ψ , ψ' , Drell-Yan and semi-leptonic $D\bar{D}$ decays) and the combinatorial background. The physical components are estimated through a fit where the shape of each component is obtained by a MonteCarlo simulation which includes the apparatus description and operation and the data reconstruction (Drell-Yan and open charm are generated at leading order using PYTHIA⁵). The combinatorial background, mostly due to π and K decays, is estimated from the like-sign muon pairs in the real data according to $N_{BG} = 2\sqrt{N^{++}N^{--}}$.

3 ψ' production in Pb-Pb collisions

NA38 and NA50 have verified that Drell-Yan is proportional to the number of elementary nucleon-nucleon interactions from p-p up to Pb-Pb collisions⁶. The ψ' production rate is therefore normalized to Drell-Yan, which, moreover, cancels out most of the systematic effects. The fit to the dimuon mass spectrum in each centrality region leads to the ψ' and the Drell-Yan yields (the latter in the mass interval $4.2 - 7.0$ GeV/ c^2), and hence to the ratio $B'_{\mu\mu}\sigma(\psi')/\sigma(DY)$, proportional to the ψ' production cross-section per elementary collision. This ratio is displayed in Fig. 1 along with the ratio $B'_{\mu\mu}\sigma(\psi')/B_{\mu\mu}\sigma(J/\psi)$, as a function of E_T . Besides the good compatibility between the two samples, it shows that the ψ' production rate is increasingly suppressed with centrality, and that the ψ' is more suppressed than J/ψ with increasing centrality.

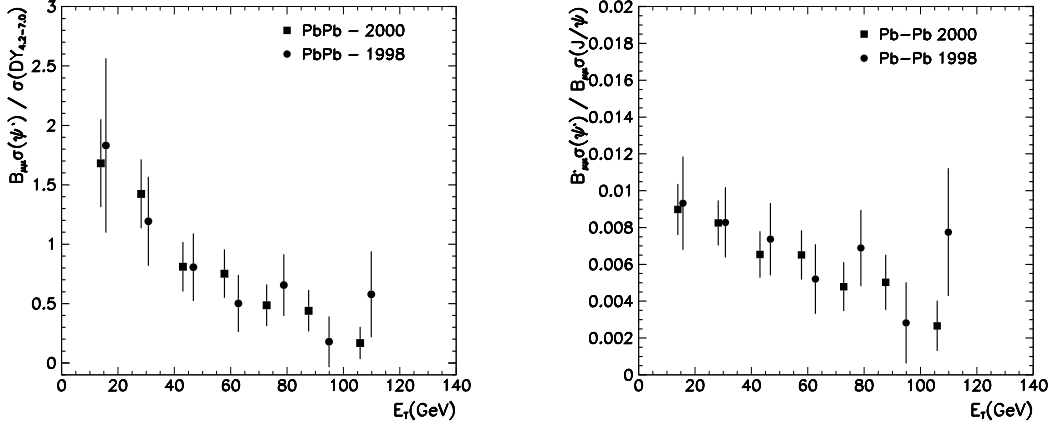


Figure 1: $B'_{\mu\mu}\sigma(\psi')/\sigma(DY)$ (left) and $B'_{\mu\mu}\sigma(\psi')/B_{\mu\mu}\sigma(J/\psi)$ (right) as a function of E_T for the Pb-Pb 1998 and 2000 data samples.

4 Comparison with lighter systems

The ψ' suppression in Pb-Pb collisions can be compared with the results obtained from both proton-induced reactions by the same NA50 experiment (at 400 and 450 GeV/c incident p momentum) and S-U reactions by the NA38 experiment (at 200A GeV/c incident Sulphur momentum). The relative suppression of the two charmonia states as a function of the product of the projectile and target atomic mass numbers A and B is shown in Fig. 2 (left). The ratio $B'_{\mu\mu}\sigma(\psi')/B_{\mu\mu}\sigma(J/\psi)$ can be parametrized with a power law $A^{\Delta\alpha}$, where α accounts for all nuclear effects. The measured negative value of $\Delta\alpha$ indicates that the ψ' is more suppressed than the J/ψ already in p-A collisions^{7,8}. Moreover the ψ' appears to be even more suppressed in ion-ion interactions. Fig. 2 (right) shows the ratio $B'_{\mu\mu}\sigma(\psi')/\sigma(DY)$ as a function of L , the

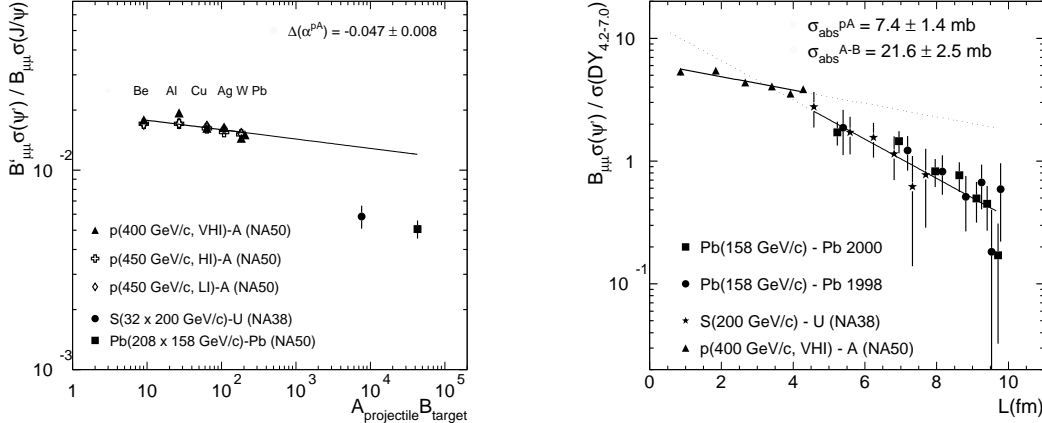


Figure 2: $B'_{\mu\mu}\sigma(\psi')/B_{\mu\mu}\sigma(J/\psi)$ as a function of $A \times B$ (left) and $B'_{\mu\mu}\sigma(\psi')/\sigma(DY)$ as a function of L (right).

mean path crossed by the $c\bar{c}$ pair in the nuclear matter (L is estimated using the Glauber model). The behaviour of the production rate is clearly different in p-A and A-B interactions. Using the parametrization $e^{-\langle\rho L\rangle\sigma_{abs}}$, where ρ is the nuclear density, we obtain $\sigma_{abs} = 7.4 \pm 1.4$ mb in p-A collisions and the much higher value $\sigma_{abs} = 21.6 \pm 2.5$ mb in ion-ion collisions. Furthermore, the ψ' suppression is the same in S-U and Pb-Pb interactions as a function of L .

5 Comparison between J/ψ and ψ' productions

Fig. 3 (left) presents updated results on the ratio $B_{\mu\mu}\sigma(J/\psi)/\sigma(DY)$ as a function of E_T in Pb-Pb collisions⁸. The superimposed absorption curve is obtained from p-A and S-U data⁸,

and the band accounts for the Drell-Yan energy rescaling uncertainties. While for peripheral collisions the data points follow the standard absorption curve, they later depart from this normal behaviour with no clear flattening at high E_T , a pattern which qualitatively agrees with the theoretically predicted anomalous J/ψ suppression. Fig. 3(right) shows the ratio of the

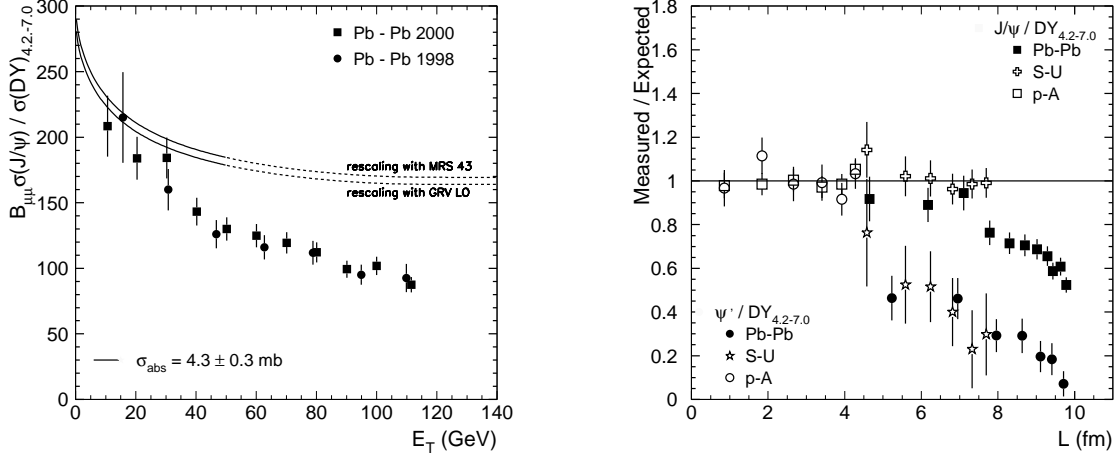


Figure 3: $B_{\mu\mu}\sigma(J/\psi)/\sigma(DY)$ as a function of E_T (left) and the ratio “measured value”/“expected value” for the relative yields $B_{\mu\mu}\sigma(J/\psi)/\sigma(DY)$ and $B'_{\mu\mu}\sigma(\psi')/\sigma(DY)$ as a function of L (right).

measured charmonia yields to the corresponding “expected” values as a function of L for various interacting systems. The expected values are computed only from normal absorption in nuclear matter, using a full Glauber calculation with $\sigma_{abs} = 4.3 \pm 0.3$ mb for the J/ψ , as extracted from a simultaneous fit to p-A and S-U data, and with $\sigma_{abs} = 7.9 \pm 0.6$ mb for the ψ' , as extracted from p-A data only (since this absorption value is incompatible with the one obtained in S-U data). The plot shows that in A-B collisions the ψ' departs from the expected absorption curve for lower L values with respect to the J/ψ .

6 Conclusions

In Pb-Pb collisions the ψ' is suppressed by a factor 7 with respect to Drell-Yan and by a factor 2.5 with respect to J/ψ between peripheral and central collisions. In comparison with lighter systems the ψ' is much more suppressed in nucleus-nucleus than in proton-nucleus interactions, and the suppression pattern is the same in S-U and Pb-Pb as a function of L . The anomalous suppression for the ψ' sets in for lower L values than for the J/ψ .

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